Arytenoid Adduction With Nerve-Muscle Pedicle Transfer vs Arytenoid Adduction With and Without Type I Thyroplasty in Paralytic Dysphonia

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IMPORTANTCE Optimal glottal closure as well as symmetrical vocal fold masses and tensions are essential prerequisites for normal voice production. Successful phonosurgery depends on restoring these prerequisites to achieve long-term improvement.

OBJECTIVE To evaluate the efficacy of the laryngeal framework surgical treatments (arytenoid adduction with and without thyroplasty type I [AA ± Th-I]) compared with arytenoid adduction combined with nerve-muscle pedicle flap transfer (AA + NMP) in unilateral vocal fold paralysis. Patterns of voice outcome were compared over a 2-year period.

DESIGN, SETTING, AND PARTICIPANTS Retrospective review of clinical records of 22 patients who presented to an institutional practice with severe paralytic dysphonia between March 1999 and December 2008, who received 2 different treatments. Postoperative follow-up was conducted over 2 years.

INTERVENTIONS Eleven patients were treated with AA ± Th-I and 11 patients were treated with AA + NMP.

MAIN OUTCOMES AND MEASURES Vocal function was evaluated preoperatively and at 3, 12, and 24 months postoperatively. Vocal parameters evaluated were jitter, shimmer, harmonics to noise ratio (HNR), maximum phonation time (MPT), and overall grade and breathiness grade of the Grade-Roughness-Breathiness-Asthenia-Strain (GRBAS) voice scale. The outcomes of voice measurements were compared within each group across time and among the 2 groups at each time point.

RESULTS All voice parameters showed initial postoperative improvement in both groups after 3 months. Moreover, the AA + NMP group showed significant steady improvement over the 2-year follow-up, which did not occur in the AA ± Th-I group. In the AA + NMP group, MPT increased from a mean (SD) of 5.4 (2.1) s at preoperative assessment to 21.5 (7.0) s at 24 months; jitter decreased from 8.6% (5.3%) to 1.2% (0.7%); shimmer decreased from 13.1% (6.0%) to 4.0% (1.6%); HNR increased from 3.8 (3.3) to 9.0 (0.8); overall grade of GRBAS decreased from 2.4 (0.9) to 0.2 (0.4); and breathiness grade of GRBAS decreased from 2.0 (1.0) to 0.1 (0.3).

CONCLUSIONS AND RELEVANCE Unlike the conventional laryngeal framework surgical treatments, AA + NMP provided long-term voice improvement with nearly normal voice quality. Thus, it can be considered an effective surgical treatment for paralytic dysphonia due to unilateral vocal fold paralysis associated with large glottal gap.

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Treatment of dysphonia due to unilateral vocal fold paralysis (UVFP) is a rich area for research. Trials of surgical treatment had begun a century ago by Brunings, who developed the first technique for vocal fold injection using paraffin, which then developed into more advantageous materials over time. Laryngeal framework surgery is the second group of surgical treatments, which includes 2 main techniques used for treating UVFP. These are thyroplasty type I (Th-I) and arytenoid adduction (AA). The third group of surgical treatments is the reinnervation techniques. The main goal of the reinnervation surgical treatments is to regain vocal fold mass and stiffness via reinnervating the thyroarytenoid muscle, which constitutes the core of the vocal fold. These techniques include nerve-muscle pedicle transfer (NMP) to the thyroarytenoid muscle, direct ansa cervicalis nerve implantation onto the thyroarytenoid muscle, and anastomosis between recurrent laryngeal nerve and a donor nerve like hypoglossal or ansa cervicalis nerves. The reinnervation techniques provided good voice results; however, their early successes have not been consistently duplicated, which prevented these techniques from gaining widespread popularity. Yumoto et al have refined the conventional NMP technique by using the sternohyoid muscle and its ansa cervicalis nerve branch for the flap instead of the omohyoid muscle. This is because the sternohyoid muscle has proven to receive more motor fibers from the ansa cervicalis loop than the omohyoid muscle. Also, AA was performed without opening the capsule of the cricoarytenoid joint.

Thyroplasty type I become the most common surgical treatment for paralytic dysphonia, either alone or combined with AA (AA + Th-I). However, long-term improvement of the perceptual voice quality following AA with and without Th-I (AA ± Th-I) have not been reported. This is because of the lack of studies that addressed repeated measurements of voice outcome over a long period following these laryngeal framework surgical treatments. The main objective of this study was to follow up the pattern of voice outcomes over a 2-year period following the refined AA + NMP compared with AA ± Th-I to determine whether the addition of NMP to AA is an improvement over AA ± Th-I.

Methods

This study was approved by the institutional review board provided by the Graduate School of Medicine, Kumamoto University, Kumamoto City, Japan. This study included 22 patients who presented with severe paralytic dysphonia due to UVFP in the period from March 1999 to December 2008. Patient profile including age, sex, etiology, and the period from onset of paralysis to surgery is given in Table 1 for both groups. All patients had large glottal gap (glottal gap ranged from grades 3 to 4). However, the patient selection criteria differed by treatment. Arytenoid adduction only was performed when the maximum width of the glottal phonatory gap was located in the posterior half of the glottis, with minimal or no gap involved in the anterior half of the membranous vocal folds. AA + Th-I is considered in laterally fixed vocal fold with glottal gap involving the anterior half of the membranous vocal fold as well as the posterior glottis during phonation. These laryngeal framework surgical treatments were carried out when the NMP technique was not possible because of severe neck scarring. When ansa cervicalis nerve exploration was possible and electromyography showed denervated thyroarytenoid muscle, AA + NMP was undertaken. In our study, 11 patients underwent modified AA + NMP with general anesthesia and 11 patients underwent AA ± Th-I. Among the 11 AA ± Th-I patients, 7 underwent AA + Th-I using GORE-TEX (W. L. Gore & Associates Inc) strip with local anesthesia to adjust the position of the GORE-TEX strip according to the perceived voice quality intraoperatively. Four patients underwent AA only with general anesthesia. Both groups underwent voice evaluation preoperatively and at 3 time points postoperatively (3, 12, and 24 months). Voice parameters measured in the study were maximum phonation time (MPT), jitter, shimmer, harmonics to noise ratio (HNR), and grade overall (G) and breathiness grade (B) of the Grade-Roughness-Breathiness-Asthenia-Strain (GRBAS) voice scale.

The voice was recorded using a Marantz Solid State Recorder (model PMD 670; Marantz). Each patient was asked to phonate into the microphone (model WM-421;
Panasonic) at a distance of 20 cm from his or her mouth. The recorded voice sample included standard text and sustained phonation of the vowel /a/. The voice was digitized at 45 kHz through an antialiasing filter and stored in pulse-code modulation format. This format keeps the original quality of voice for a long period. Speech segment (the recorded text) was trimmed and used for auditory perceptual assessment, which was conducted by 3 experienced listeners (M.M.H., E.Y., and N.K.). The voice samples were presented to the raters in random order and in an anonymous way. The mean value of G and B was calculated for each subject. Vowel segment /a/ was trimmed and 3 different seconds was analyzed with a Multi-Dimensional Voice Program (model 5105, version 3.1.7; Kay Elemetrics). The mean value of jitter, shimmer, and noise to harmonics ratio (NHR) was calculated. The NHR was converted into HNR using the following equation:

\[ \text{HNR} = 10 \times \log \frac{1}{\text{NHR}}. \]

Using a stopwatch, we measured the MPT by instructing the patient to produce sustained phonation of the vowel /a/ as long as possible at a comfortable pitch and loudness.

Because we tested the improvement of repeated voice measurements, we predicted that the significant difference between means of voice parameters, if any, should go in the direction for a parameter. If this difference was obtained in the unexpected direction, it was attributed to mere chance and viewed as a nonsignificant difference. In other words, if a voice parameter showed a change in the improvement direction over time with a nonsignificant difference or showed changes in the worsening direction with a significant difference, both were viewed as nonsignificant. Therefore, a 1-tailed paired t test was conducted among different time points within each group. However, in comparisons of voice outcomes between the 2 groups, we expected that the difference, if any, would go in either direction. Thus, a 2-tailed unpaired t test was used. Lastly, comparisons of noncontinuous data (G and B of GRBAS) within a group and between the 2 groups were carried out using the Mann-Whitney test.

### Results

#### Follow-up Over the First 3 Months After Surgery

All voice parameters measured in this study (MPT, acoustic measurements, and perceptual voice quality) improved significantly in both groups in the first 3 months after surgery. Preoperative to postoperative comparisons were not illustrated to avoid complex graphs. Instead, P values of the comparisons are given in Table 2.

#### Follow-up From 3 to 24 Months After Surgery

After the first 3 months, the pattern of further changes of vocal function varied from group to another, as described in the following subsections.

### Maximum Phonation Time

Changes in mean (SD) MPT over time showed a stationary pattern in the AA ± Th-I group between 3 and 12 months (10.5 [6.2] s and 10.6 [5.0] s, respectively) (Figure, A, and Table 3). Later, MPT showed a nonsignificant increase by 24 months (12.4 [4.0] s). These change patterns were not specific to certain treatment because it occurred in the AA only and AA + Th-I groups to nearly a similar range. In contrast, MPT in the AA + NMP group showed a steady and significant increase over the 2-year study period. Unlike the AA ± Th-I group, all patients in the AA + NMP group showed steady improvement to varying degrees. Maximum phonation time in AA + NMP group significantly improved at 24 months (21.5 [7.0] s) compared with 3-month (14.9 [5.7] s) and 12-month (17.4 [6.0] s) evaluations. Comparing MPT between the 2 groups at each time point, a significant difference was found in the preoperative evaluation (AA ± Th-I, 3.5 [1.5] s, and AA + NMP, 5.4 [2.1] s; \( P = .03 \)). This difference increased at 12 months (AA ± Th-I, 10.6 [5.0] s, and AA + NMP, 17.4 [6.0] s; \( P = .01 \)) and increased further at 24 months in favor of AA + NMP group (AA ± Th-I, 12.4 [4.0] s and AA + NMP, 21.5 [7.0] s; \( P < .001 \)).

### Table 2. Vocal Function Results: \( P \) Values of Preoperative to Postoperative Comparisons and Among Different Postoperative Time Point Comparisons in Both Groups*

<table>
<thead>
<tr>
<th>Time Point</th>
<th>MPT</th>
<th>Jitter</th>
<th>Shimmer</th>
<th>HNR</th>
<th>G</th>
<th>B</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AA ± Th-I</td>
<td>AA + NMP</td>
<td>AA ± Th-I</td>
<td>AA + NMP</td>
<td>AA ± Th-I</td>
<td>AA + NMP</td>
<td></td>
</tr>
<tr>
<td>Preop × 3 mo</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Preop × 12 mo</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Preop × 24 mo</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>3 mo × 12 mo</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>3 mo × 24 mo</td>
<td>NS</td>
<td>&lt; .001</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>12 mo × 24 mo</td>
<td>NS</td>
<td>&lt; .006</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Abbreviations: AA + NMP, arytenoid adduction combined with nerve-muscle pedicle transfer; AA ± Th-I, arytenoid adduction with and without thyroplasty type I; B, breathiness grade of GRBAS (Grade-Roughness-Breathiness-Asthenia-Strain); G, grade overall of GRBAS; HNR, harmonics to noise ratio; MPT, maximum phonation time; NS, nonsignificant; Preop, preoperation.

* Table 2 gives repeated measurements of voice parameters over time within each group. The paired t test was used for MPT, jitter, shimmer, and HNR, and the Mann-Whitney test was used for G and B.
Harmonics to Noise Ratio

In AA ± Th-I group, the HNR revealed a stationary pattern over the 2-year study period after the initial increase at 3 months (Figure, B, and Table 3). On the contrary, the HNR showed further significant increase at 12 months compared with 3 months in the AA + NMP group. Also, the HNR revealed an increase at 24 months compared with 3 months, but the difference was nonsignificant. The HNR remained more or less stationary over the second year in the AA + NMP group.

Jitter

After the initial decrease, jitter remained nearly stationary over the first year in both groups (Figure, C, and Table 3). Subsequently, it showed a nonsignificant increase in the AA ± Th-I group at 24 months. In contrast, jitter showed a further significant decrease in the AA + NMP group at 24 months. A between-group comparison of jitter at different time points revealed that jitter improved in the AA + NMP group much better than in the AA ± Th-I group at all postoperative time points.
especially in the long-term follow up (12 and 24 months). However, these differences were nonsignificant.

**Shimmer**

After the initial decrease, shimmer showed random changes over the 2-year period in the AA ± Th-I group (Figure, D, and Table 3). First, there was an increase in shimmer at 12 months, followed by a decrease at 24 months, with nonsignificant differences. In contrast, shimmer continued to decrease over the 2-year study period of the study with a steady pattern in AA + NMP group. There were significant further decreases at 12 and 24 months relative to 3 months. Although, the difference of the mean shimmer between the 2 groups increased over time, this difference remained nonsignificant.

**Auditory Perceptual Assessment (GRBAS)**

After their initial decrease, the overall grade of dysphonia (G) and breathiness (B) values decreased further at 12 months in the AA ± Th-I group (Figure, E and F, and Table 3). Nonetheless, these differences were nonsignificant. In the second year of the study, the mean G and B values increased again, and this increase occurred in both treatments in the group (AA only and AA + Th-I). Three of 4 patients who underwent AA only and 4 of 7 patients who underwent AA + Th-I showed this increase in G value. Moreover, B value increased in all AA-only patients and in 2 of 7 AA + Th-I patients in the second year. This relatively better improvement of B in the AA + Th-I patients can be explained by the positive effect of the Gore-TEX implant in approximating the membranous vocal folds. Unlike the AA ± Th-I group, the mean G and B values revealed a steady and significant decrease over the 2-year study period in the AA + NMP group. This continuous decrease of G and B values over time is clearly demonstrated in Table 2 and in the Figure, E and F. Apart from the 1 patient who did not show the steady decrease in the second year, all other patients in the AA + NMP group (n = 10) showed a steady and marked decrease in both G and B values in the 24-months follow-up. The perceptual voice quality improved much better in AA + NMP group than in the AA ± Th-I group over the 24-month follow-up with significant differences (P = .02 for G and P = .003 for B).

### Discussion

Normal voice production requires optimal glottal closure with median location of the vocal folds, symmetrical vocal fold tension and masses, and supple mucosa. The objectives of treating breathy dysphonia due to UVFP focused mainly on the reestablishment of these prerequisites. The principle of laryngeal framework surgical treatments performed for UVFP is to approximate both vocal folds in midline by adjusting the paralyzed one to the median position. The AA adds passive tension to the vocal fold; however, the active tension of the fold achieved only by reinnervation of its thyroarytenoid muscle (internal muscle tone). In the present study, voice outcomes were followed up over a 2-year period following 2 types of phonosurgical procedures. In the AA ± Th-I group, 4 patients underwent AA only simply because they did not need the adjuvant type I thyroplasty. So, the principle of the first type of treatment (AA ± Th-I) is to approximate the vocal folds and achieve median position during phonation; whereas the principle of the second type of treatment (AA + NMP) includes both vocal fold approximation and reinnervation, which restores the internal tone of thyroarytenoid muscle. The MPT improved steadily in AA + NMP group over the 24-month follow-up, while it showed only initial improvement 3 months after surgery in the AA ± Th-I group, with a more or less stationary pattern afterward. The longer MPT in AA + NMP group indicates better glottal efficiency and glottal closure during phonation. Also, the acoustic parameters (jitter, shimmer, and HNR) revealed continuous improvements over the 2-year period of study in AA + NMP group with significant differences between 3 and 24 months of follow-up. This did not occur in AA ± Th-I group, which revealed random pattern in jitter and shimmer changes and stationary pattern in HNR change over the 24-month follow-up.

In addition, the perceptual voice quality showed steady improvement over time in AA + NMP group, with marked improvement to nearly normal voice at the 24-month evaluation.

### Table 3. Outcome Measurements Over the 24-Month Follow-up*  

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Preop</th>
<th>3 mo</th>
<th>12 mo</th>
<th>24 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AA ± Th-I</td>
<td>AA + NMP</td>
<td>AA ± Th-I</td>
<td>AA + NMP</td>
</tr>
<tr>
<td>MPT, s</td>
<td>3.5 (1.5)</td>
<td>5.4 (2.1)</td>
<td>10.5 (6.2)</td>
<td>14.9 (5.7)</td>
</tr>
<tr>
<td>Jitter, %</td>
<td>9.3 (4.4)</td>
<td>8.6 (5.3)</td>
<td>3.3 (5.0)</td>
<td>1.7 (1.0)</td>
</tr>
<tr>
<td>Shimmer, %</td>
<td>14.3 (4.5)</td>
<td>13.1 (6.0)</td>
<td>7.5 (9.0)</td>
<td>6.8 (3.5)</td>
</tr>
<tr>
<td>HNR, semitones</td>
<td>4.2 (1.6)</td>
<td>3.8 (3.3)</td>
<td>7.4 (2.8)</td>
<td>8.0 (1.3)</td>
</tr>
<tr>
<td>Overall grade of GRBAS</td>
<td>2.4 (0.4)</td>
<td>2.4 (0.9)</td>
<td>0.9 (0.8)</td>
<td>0.8 (0.6)</td>
</tr>
<tr>
<td>Breathiness grade of GRBAS</td>
<td>2.3 (0.5)</td>
<td>2.0 (1.0)</td>
<td>0.6 (0.4)</td>
<td>0.6 (0.4)</td>
</tr>
</tbody>
</table>

Abbreviations: AA + NMP, arytenoid adduction combined with nerve-muscle pedicle transfer; AA ± Th-I, arytenoid adduction with and without type I thyroplasty; GRBAS, Grade-Roughness-Breathiness-Asthenia-Strain; HNR, harmonics to noise ratio; MPT, maximum phonation time; Preop, preoperation.

* Data are given as mean (SD) value.
method for determining voice outcomes than auditory perceptual assessment by experienced listeners. This can be achieved via evaluation and rating of high-quality voice recordings using the GRBAS voice scale.\textsuperscript{17,18} In our study, there are 6 of 11 patients in AA + NMP group who scored G O B O on the GRBAS voice scale at the 12-month evaluation and 8 patients scored G O B O at the 24-month evaluation. This means that 54% of patients regained their normal voice after 12 months, and 73% of patients regained their normal voice after 24 months in the AA + NMP group. On the other hand, there are 4 of 11 patients (36%) in the AA ± Th-I group who scored G O B O on the GRBAS voice scale at the 12-month evaluation and only 2 patients (18%) scored G O B O at the 24-month evaluation. The initial voice improvement in the AA ± Th-I group can be explained by achieving good glottal closure with median vocal fold position during phonation. This is usually achieved after implantation of the GORE-TEX strip intraoperatively. However, subsequent vocal fold atrophy, which is an inevitable outcome for the denervated thyroarytenoid muscle, makes the vocal fold bulk or mass decrease over time. This atrophy and decrease in the vocal fold mass led to asymmetry in mass and stiffness between the 2 vocal folds, which is the key reason for worsened voice quality over the long-term follow-up in the AA ± Th-I group.

Laryngeal framework surgical treatments such as AA and Th-I or their combination achieved good glottal closure in the median position by medialization of the paralyzed vocal fold; however, they failed to restore the tensing capability of the thyroarytenoid muscle (the main core of the vocal fold). On the other hand, the good voice outcome pattern in the AA + NMP group can be explained by the dual effect of the operation. Arytenoid adduction is responsible for the immediate voice improvement in the short-term follow-up (3 months), while NMP is responsible for the steady voice improvement over the long-term follow-up (12 and 24 months). This pattern of voice improvement can only be explained by the reinnervation process of the thyroarytenoid muscle, which maintained or restored the muscle bulk and vocal fold stiffness essential for normal mucosal vibration of the vocal folds.

In fact, to date, the combined AA + Th-I is a common treatment for UVFP, as indicated by its extensive research.\textsuperscript{19,20} These studies compared preoperative with postoperative evaluation of voice outcome; however, they failed to perform repeated voice measurements over time. The postoperative evaluations, which varied from 2 weeks,\textsuperscript{16} 6 months,\textsuperscript{20} and 12 months,\textsuperscript{19} showed significant improvement of some voice parameters compared with their preoperative values. Those look logical, but how long will that improvement last? To date, this question has not been answered yet. Following AA ± Th-I, further voice improvement over time has not been reported until the present article.

Tucker\textsuperscript{18} reported long-term voice improvement following medialization laryngoplasty combined with NMP (Th-I + NMP) using the omohyoid muscle along with its ansa cervicalis nerve supply. However, the reported voice results relied only on subjective assessment of the perceptual voice quality without any acoustic or aerodynamic parameter evaluated in his study. In the present study, we used both subjective and objective voice measurements, which are more reliable. Also, AA is superior to Th-I because it corrects the vocal fold vertical level difference and manages the posterior glottal gap. This is because the nylon threads used in AA pull on the muscular process of arytenoid in similar direction as the lateral cricoarytenoid muscle.

Yumoto et al\textsuperscript{9} introduced their modified AA + NMP technique with excellent voice results over long-term study. Voice outcome continued to improve over 24 months. Reinnervation of the thyroarytenoid muscle has proven to be essential for normal vocal fold mucosal wave traveling and hence, normal voice production. Yumoto et al\textsuperscript{21} found that thyroarytenoid contraction shifts the mucosal upheaval zone toward the tracheal side along the vocal fold length, expanding the vocal fold vibrating area. This zone represents the lower lip of the vibrating mucosa. Also, Hassan et al\textsuperscript{22} reported that voice outcome continued to improve over 2 years following the modified AA + NMP. However, none of these recent studies compared their findings with AA ± Th-I.

Conclusions

This comparative study took its importance from comparing a current common surgical treatment for paralytic dysphonia (AA ± Th-I) with a recent surgical treatment in the last 3 years (modified AA + NMP). Our findings showed that voice outcome improved in short- and long-term follow-up following AA ± NMP. The vocal function of the AA + NMP group showed marked improvement to a nearly normal voice in the majority of patients at the end of the 2-year study period. This did not occur in the AA ± Th-I group, which showed only initial postoperative improvement with random voice changes later on.

Modified AA + NMP is an effective surgical treatment for paralytic dysphonia due to UVFP associated with large glottal gap. This treatment provided better long-term voice outcome compared with AA ± Th-I.
REFERENCES


